

NBS MONOGRAPH 21

Specific Heats and Enthalpies of Technical Solids at Low Temperatures

A Compilation From the Literature



**U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS**

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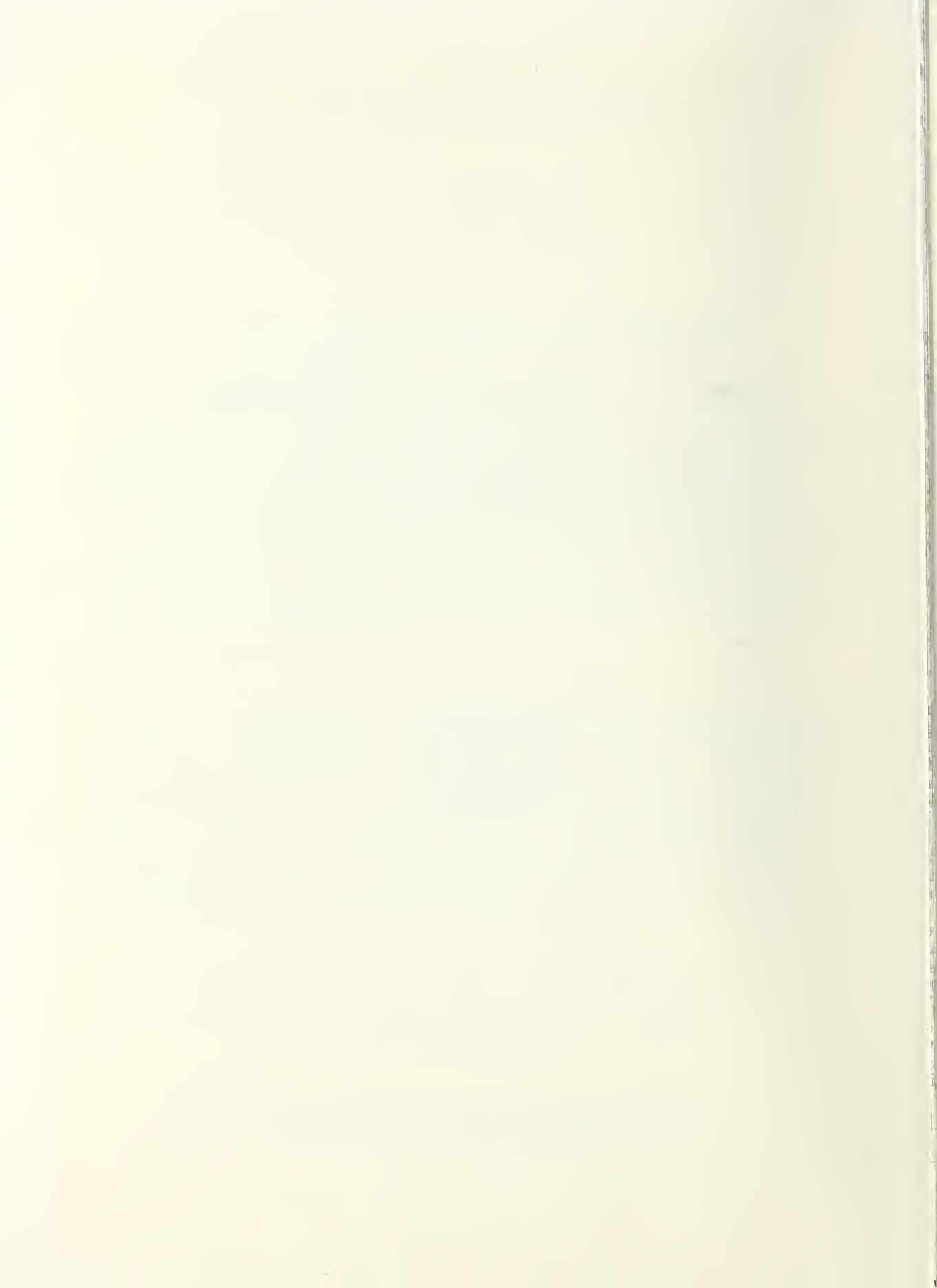
A Compilation From the Literature

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Specific Heats and Enthalpies of Technical Solids at Low Temperatures¹

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Tables are given of the specific heat, c_p , and the enthalpy of 28 metals, 3 alloys, 8 other inorganic substances, and 8 organic substances in the temperature range, 1° to 300° K.

Introduction

This publication was designed to fill a need among designers of cryogenic equipment for a compilation of heat capacity data on cryogenic materials. Previous compilations by Kelley (1950) and Schiffman (1952) are useful, but, for the present purpose, suffer from being limited to pure substances and from being presented at such widely spaced temperatures as to prevent accurate interpolation.

Our purpose has been thwarted to some extent by the distribution of available data which also favors pure substances and has led to a greater emphasis in this compilation on metallic elements than is justified by their relative usefulness (see table 1). From the engineering point of view, data are needed on many commercial alloys and plastics which are not listed in this compilation.

We have arbitrarily omitted data for the solid phases of substances which are usually used in cryogenics as fluids, i.e., helium, hydrogen, deuterium, neon, nitrogen, carbon monoxide, fluorine, argon, oxygen, air, and methane. Data on all phases of these substances are being compiled by others at this laboratory. Nor have we presented data on the superconducting state of metals unless the transition temperature was higher than 1° K.

Whenever possible, we have presented the data throughout the interval 1° to 300° K. However, the region 1° to 100° K is the region of our primary interest, and substances have been omitted for which the available data did not extend to temperatures within this range. For most engineering purposes, the enthalpy is used directly (i.e., in heat balances). Consequently, we present as our primary datum the enthalpy relative to that of the same phase at absolute zero, $H - H_0 \equiv \int_0^T c_p dT$. In a few cases, higher base temperatures had to be used. The specific heat, c_p , is less useful than the enthalpy but is also presented since it is obtained as an intermediate step.

The compilation is a critical one in that the

data presented are based on selected sources listed under each table as "Sources of above data." Other sources which may be of some current interest but which did not influence the tabulated data are listed as "Other references." Papers which are only of historical interest have not been listed. This includes most papers published before 1925. Schiffman's bibliography is quite complete and should be consulted for such references. The selection of best references will not be justified in individual cases. In general, selection was based on such factors as the precision of the data, the original authors' estimates of accuracy, the purity and state of subdivision of the samples, and whether or not heat-exchange gas was used. The use of heat-exchange gas may result in spurious heat effects due to absorption or desorption. These are significant with finely-divided samples. In addition, finely-divided samples may show size effects (Keesom and Pearlman (1956)). Another factor influencing selection was the extent of agreement with the Debye-Sommerfeld model, where applicable, with θ varying with temperature only in restricted ways illustrated, for example, by Blackman 1955 and by Keesom and Pearlman 1956.

The metals were usually measured in the annealed state. There have been a few comparative studies on cold-worked and annealed metals (see for example Maier and Anderson 1934, Martin 1960, and Eucken and Werth 1930) and one on a precipitation-hardening alloy (Otter 1959). In these studies the specific heats for the two conditions differed by zero to a few percent, the differences being not much more than the experimental precision. Cold-working lowered the specific heat. We may conclude that the effect of varying physical condition will not usually be significant in the uses envisioned for this compilation.

Smoothing and interpolation were necessary in many cases. At the lower temperatures, the following equation was used for many of the substances in the normal state:

$$c_p = \gamma T + aD(\theta/T)$$

In this, $D(\theta/T)$ is the Debye specific heat function and γ and a are constants. The parameter θ is

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derived from the experimental points and is a weak function of temperature. It was smoothed graphically and substituted back into the equation at the desired values of T . At higher temperatures, smoothing and interpolation were done graphically. In some cases high-temperature data from Kelley's 1949 compilation were taken into account in establishing the trend of the specific heat values at ambient temperature.

Table 3 gives the constants of the Debye-Sommerfeld equation in the limit of zero temperature,

$$c_v = \gamma T + \alpha T^3; \quad \alpha = 12\pi^4 R / 5\theta_0^3$$

for some of the substances in the normal state, as well as the maximum temperature to which the equation can be used with the limiting value of θ .

Although an accuracy of 1 percent is adequate for most engineering uses, the number of significant figures presented in the specific heat is usually sufficient to preserve the accuracy of the original data. This accuracy is at best about 1 percent up to 20° K and 0.2 percent above 40° K. However, in many cases, only data of lower accuracy were available. The enthalpy is given to more places than its absolute accuracy warrants in order to avoid loss of accuracy in taking small differences.

Regarding units, the intended technical utilization, as well as the presence of alloys and plastics in the compilation, clearly dictated a mass rather than molar basis. Beyond this, our choice was simplified by a requirement that centimeter-gram-second system units be used. Many engineers prefer British units, but those engaged in cryogenics often find it convenient to mix metric and British units. Since it was obviously not possible to please everyone, we have contented ourselves with being self-consistent. Conversion factors are given in table 2. In converting from other energy units and temperature scales, we have observed, whenever possible, the distinctions between the various kinds of calories and the various values of the number relating the Kelvin and Celsius scales that have been used, even though the effects were much smaller than the usual calorimetric uncertainties.

The bibliography is believed to be complete for the period 1930 to 1958. The literature search was based on Physics Abstracts and Chemical Abstracts for those years not covered by the bibliographies of Kelley and Schiffman.

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TABLE 1. *List of Substances*

<i>Metals</i>	<i>Metals (Continued)</i>	<i>Other Inorganic Substances</i>
Aluminum	Silicon	Carbon dioxide
Beryllium	Silver	Charcoal, activated
Bismuth	Sodium	Diamond
Cadmium	Tantalum	Graphite
Chromium	Tin (white)	Ice
Copper	Titanium	Magnesium oxide, MgO
Germanium	Tungsten	Pyrex glass
Gold	Zinc	Quartz, SiO ₂
Indium		Silica glass, SiO ₂
α -Iron	<i>Alloys</i>	<i>Organic Substances</i>
γ -Iron	Constantan	Araldite
Lead	Monel	Bakelite varnish
Magnesium	Wood's metal	Glyptal
α -Manganese	63S Aluminum alloy	GR-S rubber
β -Manganese		Lucite
γ -Manganese		Natural rubber hydro-carbon
Mercury		Polyethylene
Molybdenum		Polystyrene
Nickel		Polyvinyl alcohol
Niobium		Teflon
Palladium		
Platinum		
Rhodium		

TABLE 2. *Conversion Factors*

<i>To Convert j/g to—</i>	<i>Multiply by—</i>
j/lb	453.6
Btu/lb	0.4299
cal/g	.2390

TABLE 3. *Constants of Debye-Sommerfeld equation*

$$C_s = \gamma T + \alpha T^2; \quad \alpha = 12\pi^4 R / 5 \Theta_D^3; \quad 0 < T < T_{\max}$$

Substance	$10^6 \gamma$	γ	$10^6 \alpha$	Θ_D	T_{\max}
<i>Metals:</i>	<i>jg⁻¹deg⁻²K</i>	<i>mjg-atom⁻¹deg⁻²K</i>	<i>jg⁻¹deg⁻⁴K</i>	<i>deg K</i>	<i>deg K</i>
Aluminum.....	50.4	1.36	0.93	426	4
Beryllium.....	25	0.226	.138	1160	20
Bismuth.....	0.32	.067	5.66	118	2
Cadmium.....	5.6	.63	2.69	186	3
Chromium.....	28.3	1.47	0.165	610	4
Copper.....	10.81	0.687	.746	344.5	10
Germanium.....	(a)	(a)	.528	370	2
Gold.....	3.75	0.74	2.19	165	15
Indium.....	15.8	1.81	13.1	109	2
α Iron.....	90	5.0	0.349	464	10
Lead.....	15.1	3.1	10.6	96	4
Magnesium.....	54	1.32	1.19	406	4
α Manganese.....	251	13.8	0.328	476	12
Molybdenum.....	23	2.18	.238	440	4
Nickel.....	120	7.0	.39	440	4
Niobium.....	85	7.9	.64	320	1
Palladium.....	98	10.5	.89	274	4
Platinum.....	34.1	6.7	.72	240	3
Rhodium.....	48	4.9	.173	478	4
Silicon.....	(a)	(a)	.263	640	4
Silver.....	5.65	0.610	1.58	225	4
Sodium ^a	60	1.37	21.4	158	4
Tantalum.....	31.5	5.7	0.69	250	4
Tin (white).....	14.7	1.75	2.21	195	2
Titanium.....	71	3.4	0.54	420	10
Tungsten.....	7	1.3	.16	405	4
Zinc.....	9.6	0.63	1.10	300	4
<i>Alloys:</i>					
Constantan ^a	113	6.9	0.56	384	15
Monel ^a	108	6.5	.62	374	20
<i>Other inorg. subs.:</i>					
Diamond.....	-----	-----	0.0152	2200	50
Ice.....	-----	-----	15.2	192	10
Pyrex.....	-----	-----	3.14	-----	5
<i>Organic subs.:</i>					
Glyptal.....	-----	-----	27	-----	4
Lucite.....	-----	-----	35	-----	4
Polystyrene.....	-----	-----	63	-----	4

^a See notes under table 4.

TABLE 4. *Specific heat and enthalpy*

Metals

<i>T</i>	Aluminum		Beryllium		Bismuth		Cadmium	
	<i>C_p</i>	<i>H-H₀</i>	<i>C_p</i>	<i>H-H₀</i>	<i>C_p</i>	<i>H-H₀</i>	<i>C_p</i>	<i>H-H₀</i>
° K	<i>jq⁻¹deg⁻¹ K</i>	<i>jq⁻¹</i>	<i>jq⁻¹deg⁻¹ K</i>	<i>jq⁻¹</i>	<i>jq⁻¹deg⁻¹ K</i>	<i>jq⁻¹</i>	<i>jq⁻¹deg⁻¹ K</i>	<i>jq⁻¹</i>
1	0.000 10 ^a							
1	.000 051	0.000 025	0.000 025	0.000 013	0.000 00598	0.000 00158	0.000 008	0.000 003
2	.000 108	.000 105	.000 051	.000 051	.000 0461	.000 0233	.000 033	.000 022
3	.000 176	.000 246	.000 079	.000 116	.000 170	.000 123	.000 090	.000 082
4	.000 261	.000 463	.000 109	.000 209	.000 493	.000 432	.000 21	.000 22
6	.000 50	.001 21	.000 180	.000 496	.002 14	.002 88	.001 30	.001 5
8	.000 88	.002 6	.000 271	.000 944	.005 47	.010 2	.004 3	.007 0
10	.001 4	.004 9	.000 389	.001 60	.010 4	.025 9	.008 0	.019
15	.004 0	.018	.000 842	.004 57	.023 8	.111	.025	.102
20	.008 9	.048	.001 61	.010 5	.036 3	.262	.046	.28
25	.017 5	.112	.002 79	.021 2	.047 7	.472	.066	.56
30	.031 5	.232	.004 50	.039 2	.057 2	.734	.086	.94
35	.051 5	.436						
40	.077 5	.755	.009 96	.109	.072 7	1.38	.117	1.96
50	.142	1.85	.019 2	.253	.084 6	2.17	.141	3.26
60	.214	3.64	.034 1	.523	.093 5	3.06	.159	4.76
70	.287	6.15	.056 2	.971	.100	4.03	.172	6.43
80	.357	9.37	.090 6	1.69	.105	5.05	.182	8.20
90	.422	13.25	.139	2.82	.108	6.12	.190	10.1
100	.481	17.76	.199	4.51	.111	7.21	.196	12.0
120	.580	28.4	.345	9.87	.114	9.45	.205	16.0
140	.654	40.7	.525	18.5	.116	11.8	.211	20.2
160	.713	54.4	.723	31.0	.118	14.1	.215	24.4
180	.760	69.2	.921	47.4	.119	16.5	.219	28.8
200	.797	84.8	1.11	67.8	.120	18.9	.222	33.2
220	.826	101.0	1.29	91.8	.121	21.3	.224	37.6
240	.849	117.8	1.47	120	.122	23.7	.226	42.1
260	.869	135.0	1.64	151	.122	26.2	.228	46.7
280	.886	152.5	1.81	185	.123	28.6	.229	51.2
300	.902	170.4	1.97	223	.124	31.1	.230	55.8
Sources of above data	Giauque & Meads 1941 Maier & Anderson 1934 Phillips 1958		Critescu & Simon 1934 Hill & Smith 1953		Anderson 1930 Armstrong & Grayson-Smith 1949 Bronson & MacHattie 1938 Kalinkina & Strelkov 1958 Keesom & Pearlman 1954 Keesom & van den Ende 1931		Bronson & Wilson 1936 Craig, Krier, Coffer, Bates, & Wallace 1954 Smith 1955	
Other refs.	Goodman 1955, 1957 Kok & Keesom 1937		Lewis 1929 Simon & Ruhemann 1927		Ramanathan & Srinivasan 1955		Lange & Simon 1928 Rodebush 1923	

See notes at end of table.

TABLE 4. *Specific heat and enthalpy—Continued*

Metals—Continued

<i>T</i>	Chromium		Copper		Germanium ^b		Gold	
	<i>C_p</i>	<i>H-H₀</i>	<i>C_p</i>	<i>H-H₀</i>	<i>C_p</i>	<i>H-H₀</i>	<i>C_p</i>	<i>H-H₀</i>
° K	<i>fg</i> -1deg -1 K	<i>fg</i> -1	<i>fg</i> -1deg -1 K	<i>fg</i> -1	<i>g</i> -1deg -1 K	<i>fg</i> -1	<i>fg</i> -1deg -1 K	<i>fg</i> -1
1	0.000 0285	0.000 0142	0.000 012	0.000 006	0.000 000 528	0.000 000 132	0.000 006	0.000 002
2	.000 058	.000 0573	.000 028	.000 025	.000 004 23	.000 002 11	.000 025	.000 016
3	.000 089	.000 131	.000 053	.000 064	.000 014 4	.000 010 7	.000 070	.000 061
4	.000 124	.000 237	.000 091	.000 13	.000 034 4	.000 034 3	.000 16	.000 17
6	.000 206	.000 567	.000 23	.000 44	.000 125	.000 179	.000 50	.000 78
8	.000 312	.001 07	.000 47	.001 12	.000 335	.000 612	.001 2	.002 4
10	.000 451	.001 82	.000 86	.002 4	.000 813	.001 69	.002 2	.005 6
15	.001 02	.005 28	.002 7	.010 7	.004 45	.013 6	.007 4	.028
20	.002 10	.012 8	.007 7	.034	.012 5	.054 0	.015 9	.086
25	.003 92	.027 4	.016	.090	.024 0	.145	.026 3	.191
30	.006 83	.053 2	.027	.195	.036 6	.296	.037 1	.349
40	.017 1	.163	.060	.61	.061 7	.786	.057 2	.821
50	.035 8	.421	.099	1.40	.085 8	1.52	.072 6	1.47
60	.062 1	.904	.137	2.58	.108	2.50	.084 2	2.25
70	.093	1.68	.173	4.13	.131	3.70	.092 8	3.14
80	.127	2.77	.205	6.02	.153	5.12	.099 2	4.10
90	.161	4.21	.232	8.22	.173	6.74	.104 3	5.12
100	.193	5.98	.254	10.6	.191	8.55	.108 3	6.18
120	.249	10.4	.288	16.1	.222	12.7	.113 7	8.41
140	.296	15.9	.313	22.1	.247	17.4	.117 5	10.72
160	.332	22.2	.332	28.5	.264	22.5	.120 2	13.10
180	.361	29.1	.346	35.3	.278	27.9	.122 1	15.52
200	.385	36.6	.356	42.4	.289	33.6	.123 5	17.98
220	.404	44.5	.364	49.6	.299	39.5	.124 7	20.46
240	.419	52.7	.371	56.9	.307	45.5	.125 7	22.96
260	.431	61.2	.376	64.4	.313	51.7	.126 7	25.49
280	.441	70.0	.381	72.0	.318	58.0	.127 6	28.03
300	.450	78.9	.386	79.6	.322	64.4	.128 5	30.59
Sources of above data	Anderson 1937 Rayne & Kemp 1956 Wolcott 1955		Corak, Garfunkel, Satterthwaite, & Wexler 1955 Dockerty 1933, 1937 Rayne 1956		Estermann & Weertmann 1952 Flubacher, Leadbetter, & Morrison 1959 Keesom & Seidel 1959		Corak, Garfunkel, Satterthwaite, & Wexler 1955 Geballe & Giauque 1952	
Other refs.	Estermann, Friedberg, & Goldman 1952 Simon & Ruhemann 1927 Weertman, Burk & Goldman 1952		Aoyama & Kanda 1941 Estermann, Friedberg, & Goldman 1952 Eucken & Werth 1930 Giauque & Meads 1941 Kok & Keesom 1936 Maier & Anderson 1934 Phillips 1958		Aigrain & Dugas 1950 Clusius & Piesbergen Critescu & Simon 1934 Estermann & Friedberg 1952 Hill & Parkinson 1932 Keesom & Pearlman 1953		Clusius & Hartek 1928	

See notes at end of table.

TABLE 4. *Specific heat and enthalpy—Continued*

Metals—Continued

<i>T</i>	Indium		α -Iron ^c		γ -Iron ^d		Lead	
	<i>C_p</i>	<i>H-H₀</i>	<i>C_p</i>	<i>H-H₀</i>	<i>C_p</i>	<i>H-H₂₀</i>	<i>C_p</i>	<i>H-H₀</i>
^o K	<i>jg⁻¹deg⁻¹ K</i>	<i>jg⁻¹</i>	<i>jg⁻¹deg⁻¹ K</i>	<i>jg⁻¹</i>	<i>jg⁻¹deg⁻¹ K</i>	<i>jg⁻¹</i>	<i>jg⁻¹deg⁻¹ K</i>	<i>jg⁻¹</i>
1	0.000 029	0.000 011	0.000 090	0.000 045			0.000 026	0.000 010
1	.000 019	.000 006					.000 012	.000 003
2	.000 138	.000 085	.000 183	.000 181			.000 12	.000 07
2	.000 141	.000 073					.000 09	.000 05
3	.000 410	.000 341	.000 279	.000 412			.000 33	.000 28
3	.000 464	.000 357					.000 31	.000 23
* 3.40	.000 584	.000 537						
3.40	.000 669	.000 581						
4							.000 7	.000 8
4	.000 95	.000 99	.000 382	.000 742			.000 7	.000 7
5							.001 5	.001 8
5							.001 5	.001 8
6							.002 9	.003 9
6	.003 59	.005 20	.000 615	.001 73			.003 0	.004 0
7							.004 8	.008
7							.005 0	.008
8	.008 55	.017 0	.000 90	.003 23			.007 3	.014
10	.015 5	.040 8	.001 24	.005 37			.013 7	.034
15	.036 7	.170	.002 49	.014 5			.033 5	.150
20	.060 8	.413	.004 5	.031 6	0.007	0	.053 1	.368
25	.085 7	.778	.007 5	.061			.068 1	.672
30	.108	1.265	.012 4	.110	.016	.11	.079 6	1.042
40	.141	2.52	.029	.31	.041	.39	.094 4	1.920
50	.162	4.04	.055	.73	.090	1.0 ₂	.103	2.91
60	.176	5.73	.087	1.43	.13 ₇	2.1 ₆	.108	3.97
70	.186	7.53	.121	2.46	.18 ₀	3.7 ₅	.112	5.07
80	.193	9.42	.154	3.84	.21 ₈	5.7 ₄	.114	6.20
90	.198	11.38	.186	5.55	.25 ₅	8.1 ₁	.116	7.35
100	.203	13.39	.216	7.56	.28 ₈	10.8	.118	8.53
120	.211	17.53	.267	12.40	.34 ₅	17.1	.120	10.91
140	.217	21.81	.307	18.16	.38 ₉	24.4	.121	13.32
160	.220	26.18	.339	24.63	.42 ₇	32.6	.123	15.76
180	.223	30.61	.364	31.67	.45 ₀	41.4	.124	18.22
200	.225	35.08	.384	39.2	.47 ₀	50.6	.125	20.71
220	.227	39.59	.401	47.0			.126	23.21
240	.229	44.14	.415	55.2			.127	25.73
260	.230	48.72	.428	63.6			.128	28.28
280	.232	53.34	.439	72.3			.129	30.85
300	.233	58.0	.447	81.1			.130	33.43
Sources of above data	Clement & Quinell 1953 Clusius & Schachinger 1952		Duyckaerts 1939 Keesom & Kurrelmeyer 1939 Kelley 1943		Eucken & Werth 1930		Horowitz, Silvidi, Malaker, & Daunt 1952 Meads, Forsythe, & Giaquie 1941	
Other refs.	Clement & Quinell 1950, 1952		Austin 1932 Eucken & Werth 1930 Rodebush & Michalek 1925 Simon 1928 Simon & Swain 1935				Bronson & Wilson 1936 Clement & Quinell 1952 Dolacek 1955, 1958 Keesom & van den Ende 1928, 1930, 1931 Mendelssohn & Simon 1932 Simon 1924	

See notes at end of table.

TABLE 4. *Specific heat and enthalpy—Continued*

Metals—Continued

<i>T</i>	Magnesium		α -Manganese ^{f g}		γ -Manganese ^h		Mercury	
	<i>C_p</i>	<i>H—H₀</i>	<i>C_p</i>	<i>H—H₀</i>	<i>C_p</i>	<i>H—H₀</i>	<i>C_p</i>	<i>H—H₀</i>
^o K	<i>jq⁻¹deg⁻¹ K</i>	<i>jq⁻¹</i>	<i>jq⁻¹deg⁻¹ K</i>	<i>jq⁻¹</i>	<i>jq⁻¹deg⁻¹ K</i>	<i>jq⁻¹</i>	<i>jq⁻¹deg⁻¹ K</i>	<i>jq⁻¹</i>
1	0.000 055	0.000 027	0.000 25	0.000 13			0.000 036	0.000 0125
1							^a .000 029	^a .000 0042
2	.000 117	.000 112	.000 50	.000 50			.000 480	.000 184
2							^a .000 480	^a .000 175
3							.002 07	.001 37
3	.000 19	.000 26	.000 75	.001 12			^a .002 09	^a .001 38
4							.004 09	.004 38
4	.000 29	.000 50	.001 01	.002 01			^a .004 17	^a .004 45
4								
14.16							.004 63	.005 07
4.16							^a .004 71	^a .005 16
6	.000 59	.001 36	.001 56	.004 6			.010 9	.019 4
8	.001 08	.003 00	.002 16	.008 3			.017 5	.047 7
10	.001 9	.005 9	.002 82	.013 3			.023 5	.088 6
15	.005 8	.023 7	.005 2	.032 7			.038 0	.243
20	.015	.074	.009 0	.067			.051 5	.468
25	.032	.189	.014 7	.126	0.01	0.05	.063 3	.756
30	.059	.415	.023	.219			.073 7	1.10
35	.095	.795			.025	.19		
40	.138	1.37	.050	.57	.053	.55	.089 5	1.92
50	.235	3.23	.087	1.25	.092	1.27	.099 3	2.87
60	.336	6.10	.129	2.32	.133	2.39	.107	3.90
70	.430	9.9	.171	3.82	.172	3.92	.112	4.99
80	.513	14.6	.214	5.75	.208	5.82	.116	6.13
90								
95	.586	20.1	.257	8.11	.240	8.06	.118	7.30
100			^f .273	^f 9.44				
100	.646	26.3	.267	10.79	.270	10.61	.121	8.50
120	.741	40.2	.312	16.6	.318	16.5	.125	11.0
140	.812	55.8	.349	23.2	.356	23.3	.128	13.5
160								
160	.862	72.5	.379	30.5	.386	30.7	.130	16.1
180	.901	90.2	.402	38.3	.410	38.6	.133	18.7
200	.932	108.5	.420	46.5	.430	47.0	.136	21.4
220	.955	127.4	.435	55.1	.447	55.8	.139	24.1
234.3							.142	26.1
234.3								
240	.975	146.7	.448	63.9	.463	64.9	.142	37.6
260	.992	166.4	.460	73.0	.477	74.3	.141	38.4
280	1.007	186.4	.470	82.3	.490	84.0	.140	41.2
300	1.021	206.7	.480	91.8	.503	93.9	.139	44.0
							.139	46.8
Sources of above data	Craig, Krier, Coffey, Bates, & Wallace 1954 Smith 1955		Booth, Hoare, & Murphy, 1955 Guthrie, Friedberg, & Goldman 1955 Sbomate 1945		Sbomate 1945		Busey & Gianque 1953 Misener 1940 Smith & Wolcott 1956	
Other refs.	Clusius & Vaughn 1930 Estermann, Friedberg, & Goldman 1952		Armstrong & Grayson-Smith 1949 Elson, Grayson-Smith, & Wilhelm 1940 Kelley 1939 Wolcott 1955				Carpenter & Stoodley, 1930 Maxwell & Lutes 1954 Pickard & Simon 1948 Simon 1922, 1923	

See notes at end of table.

TABLE 4. *Specific heat and enthalpy*—Continued

Metals—Continued

<i>T</i>	Molybdenum		Nickel		Niobium ^k		Palladium	
	<i>C_p</i>	<i>H-H₀</i>	<i>C_p</i>	<i>H-H₀</i>	<i>C_p</i>	<i>H-H₀</i>	<i>C_p</i>	<i>H-H₀</i>
°K	<i>jq⁻¹ deg⁻¹ K</i>	<i>jq⁻¹</i>	<i>jq⁻¹ deg⁻¹ K</i>	<i>jq⁻¹</i>	<i>jq⁻¹ deg⁻¹ K</i>	<i>jq⁻¹</i>	<i>jq⁻¹ deg⁻¹ K</i>	<i>jq⁻¹</i>
1	0.000 0229	0.000 0105	0.000 120	0.000 060	0.000 09	0.000 04	0.000 099	0.000 0493
2	.000 0472	.000 0445	.000 242	.000 241	.000 18	.000 17	.000 203	.000 200
3					^a .000 015	^a .000 005		
3	.000 0745	.000 105	.000 369	.000 546	.000 28	.000 40	.000 318	.000 459
3					^a .000 088	^a .000 049		
4	.000 106	.000 194	.000 503	.000 98	.000 40	.000 73	.000 447	.000 840
4					^a .000 27	^a .000 22		
5					.000 56	.001 20		
5					^a .000 56	^a .000 62		
6	.000 191	.000 484	.000 82	.002 28	.000 77	.001 86	.000 891	.002 31
6					^a .000 98	^a .001 38		
7					.001 02	.002 75		
7					^a .001 5	^a .002 6		
8	.000 317	.000 981	.001 19	.004 28	.001 4	.003 93	.001 41	.004 60
8					^a .002 3	^a .004 5		
9					.001 7	.005 5		
9					^a .003 2	^a .007 2		
10	.000 498	.001 78	.001 62	.007 1	.002 2	.007 4	.002 10	.008 07
15	.001 31	.006 10	.003 1	.018 5	.005 5	.026	.004 71	.024 5
20	.002 87	.016 1	.005 8	.041	.011 3	.066	.009 22	.058 6
25	.005 77	.037 4	.010 1	.079	.021	.145	.016 0	.120
30	.009 60	.072 9	.016 7	.145	.035	.28	.025 8	.223
40	.023 6	.232	.038 1	.413	.068	.80	.050 7	.600
50	.041 0	.554	.068 2	.937	.099	1.63	.077 7	1.24
60	.061 9	1.07	.103	1.79	.127	2.76	.101	2.14
70	.083 8	1.80	.139	3.00	.152	4.2	.122	3.26
80	.104	2.74	.173	4.56	.173	5.8	.139	4.56
90	.123	3.88	.204	6.45	.189	7.6	.154	6.03
100	.139	5.20	.232	8.63	.202	9.6	.167	7.63
120	.168	8.27	.278	13.76	.221	13.8	.188	11.2
140	.187	11.8	.314	19.70	.234	18.3	.202	15.1
160	.202	15.7	.342	26.28	.243	23.1	.213	19.2
180	.213	19.9	.365	33.35	.249	28.0	.221	23.6
200	.222	24.2	.383	40.82	.254	33.1	.227	28.1
220	.229	28.7	.397	48.6	.258	38.2	.232	32.6
240	.236	33.4	.410	56.7	.261	43.4	.236	37.3
260	.240	38.1	.422	65.0	.264	48.6	.239	42.1
280	.243	43.0	.433	73.6	.266	53.9	.241	46.9
300	.246	47.9	.445	82.4	.268	59.2	.243	51.7
Sources of above data	Horowitz & Daunt 1953 Rayne 1954 Simon & Zeidler 1926		Busey & Giauque 1952 Keesom & Clark 1935 Rayne & Kemp 1956		Chou, White, & Johnston 1958		Clusius & Schachinger 1947 Hoare & Yates 1957 Pickard & Simon 1948 Rayne 1954	
Other refs.			Clusius & Goldman 1936 Duyckaerts 1945 Eucken & Werth 1930 Keesom & Kok 1936		Brown, Zemansky, & Boorse 1952		Hoare 1955 Pickard 1936	

See notes at end of table.

TABLE 4. *Specific heat and enthalpy*—Continued

Metals—Continued

<i>T</i>	Platinum		Rhodium		Silicon ¹		Silver	
	<i>C_p</i>	<i>H-H₀</i>	<i>C_p</i>	<i>H-H₀</i>	<i>C_p</i>	<i>H-H₀</i>	<i>C_p</i>	<i>H-H₀</i>
^{°K}	<i>jq⁻¹ deg⁻¹ K</i>	<i>jq⁻¹</i>	<i>jq⁻¹ deg⁻¹ K</i>	<i>jq⁻¹</i>	<i>jq⁻¹ deg⁻¹ K</i>	<i>jq⁻¹</i>	<i>jq⁻¹ deg⁻¹ K</i>	<i>jq⁻¹</i>
1	0.000 035	0.000 0175	0.000 048	0.000 024	0.000 000 263	0.000 000 0658	0.000 0072	0.000 0032
2	.000 074	.000 071	.000 097	.000 096	.000 002 10	.000 001 05	.000 0239	.000 0176
3	.000 122	.000 168	.000 147	.000 218	.000 007 09	.000 005 32	.000 0595	.000 0574
4	.000 186	.000 320	.000 201	.000 392	.000 016 8	.000 016 8	.000 124	.000 146
6	.000 37	.000 85	.000 32	.000 91	.000 059 6	.000 085 3	.000 39	.000 62
8	.000 67	.001 88	.000 47	.001 70	.000 140	.000 279	.000 91	.001 87
10	.001 12	.003 65	.000 65	.002 81	.000 275	.000 679	.001 8	.004 52
15	.003 3	.013 5	.001 35	.007 65	.001 09	.003 74	.006 4	.023 3
20	.007 4	.039 5	.002 71	.017 4	.003 37	.013 8	.015 5	.076
25	.013 7	.092	.005 61	.037 3	.008 49	.042 3	.028 7	.185
30	.021 2	.182	.010 6	.077 1	.017 1	.105	.044 2	.368
40	.038	.48	.026 6	.256	.044 0	.400	.078	.979
50	.055	.95	.048 9	.633	.078 5	1.00	.108	1.91
60	.068	1.56	.072 4	1.238	.115	1.97	.133	3.12
70	.079	2.29	.094	2.07	.152	3.31	.151	4.54
80	.088	3.12	.114	3.11	.188	5.01	.166	6.13
90	.094	4.02	.132	4.34	.224	7.06	.177	7.85
100	.100	5.01	.147	5.74	.259	9.47	.187	9.67
120	.109	7.10	.171	8.93	.328	15.3	.200	13.55
140	.116	9.37	.189	12.54	.395	22.6	.209	17.65
160	.121	11.8	.202	16.46	.455	31.1	.216	21.91
180	.125	14.2	.212	20.60	.509	40.7	.221	26.29
200	.127	16.7	.220	24.92	.556	51.4	.225	30.75
220	.129	19.3	.226	29.38	.597	62.9	.228	35.28
240	.130	21.9	.232	33.96	.632	75.2	.231	39.86
260	.131	24.5	.236	38.63	.663	88.1	.234	44.50
280	.132	27.1	.240	43.38	.691	102	.235	49.20
300	.133	29.8	.243	48.2	.714	116	.236	53.91
Sources of above data	Kok & Keesom 1936 Ramanathan & Srinivasan 1959 Simon & Zeidler 1926		Clusius & Losa 1955 Wolcott 1955		Flubacher, Leadbetter, & Morrison 1959 Keesom & Seidel 1959		Corak, Garfunkel, Satterthwaite, & Wexler 1955 Meads, Forsythe, & Glanque 1941 Rayne 1956	
Other refs.	Rayne 1954				Anderson 1930 Pearlman & Keesom 1952		Eucken, Clusius, & Woitineck 1931 Keesom & Kok 1932, 1934 Keesom & Pearlman 1955 Mendelssohn & Closs 1932 Hoare & Yates 1957	

See notes at end of table.

TABLE 4. *Specific heat and enthalpy*—Continued

Metals—Continued

<i>T</i>	Sodium ^m		Tantalum		Tin (white)		Titanium	
	<i>C_p</i>	<i>H-H₀</i>	<i>C_p</i>	<i>H-H₀</i>	<i>C_p</i>	<i>H-H₀</i>	<i>C_p</i>	<i>H-H₀</i>
^o <i>K</i>	<i>fg</i> ^{-1deg} ⁻¹ <i>K</i>	<i>fg</i> ⁻¹	<i>fg</i> ^{-1deg} ⁻¹ <i>K</i>	<i>fg</i> ⁻¹	<i>fg</i> ^{-1deg} ⁻¹ <i>K</i>	<i>fg</i> ⁻¹	<i>fg</i> ^{-1deg} ⁻¹ <i>K</i>	<i>fg</i> ⁻¹
1	0.000 081	0.000 035	0.000 032	0.000 016	0.000 0170	0.000 0079	0.000 071	0.000 035
2			0.000 0063	0.000 0021	0.000 0041	0.000 0009		
2	.000 289	.000 204	.000 065	.000 065	.000 047	.000 0383	.000 146	.000 143
2			0.000 054	0.000 026	0.000 048	0.000 0228		
3								
3	.000 76	.000 70	.000 112	.000 155	.000 109	.000 113	.000 226	.000 329
ⁿ 3.72			0.000 178	0.000 138	0.000 151	0.000 116		
3.72					.000 198	.000 221		
					0.000 285	0.000 270		
4								
4	.001 60	.001 84	.000 171	.000 295	.000 245	.000 283	.000 317	.000 599
^o 4.39			0.000 352	0.000 400				
4.39			.000 201	.000 368				
			0.000 433	0.000 553				
5	.002 98	.004 08			.000 54	.000 65		
6	.005 1	.008 1	.000 333	.000 776	.001 27	.001 51	.000 54	.001 45
8	.012 2	.024 7	.000 648	.001 73	.004 2	.006 8	.000 84	.002 81
10	.023 8	.060 2	.001 17	.003 52	.008 1	.019 0	.001 26	.004 89
12	.039 7	.123						
14	.063	.225						
15			.003 60	.014 5	.022 6	.093	.003 3	.015 6
16	.093	.380						
18	.124	.597						
20	.155	.875	.008 23	.043 2	.040	.251	.007 0	.040
25	.259	1.90	.015 3	.102	.058	.498	.013 4	.090
30	.364	3.45	.024 0	.202	.076	.834	.024 5	.182
40	.544	8.03	.043 0	.540	.106	1.75	.057 1	.581
50	.695	14.2	.060 4	1.06	.130	2.93	.099 2	1.358
60	.793	21.7	.075 4	1.74	.148	4.33	.146 7	2.592
70	.86	30.0	.087 9	2.56	.162	5.88	.189	4.27
80	.91	38.9	.097 6	3.49	.173	7.55	.230	6.37
90	.95	48.2	.105	4.50	.182	9.33	.267	8.86
100	.98	57.9	.111	5.58	.189	11.18	.300	11.69
120	1.03	78.0	.119	7.88	.198	15.05	.352	18.24
140	1.06	98.9	.125	10.4	.204	19.1	.391	25.69
160	1.09	120.5	.128	12.9	.208	23.2	.422	33.84
180	1.12	142.6	.131	15.5	.212	27.4	.446	42.54
200	1.14	165.2	.134	18.1	.214	31.7	.465	51.66
220	1.16	188.2	.136	20.8	.216	36.0	.480	61.11
240	1.18	211.6	.137	23.6	.218	40.3	.493	70.84
260	1.20	235.4	.138	26.3	.220	44.7	.504	80.82
280	1.22	259.6	.139	29.1	.221	49.1	.514	91.01
300	1.24	284.2	.140	31.9	.222	53.6	.522	101.39
Sources of above data	Eastman & Rodebush 1918 Roberts 1957 Simon & Zeidler 1926		Kelley 1940 White, Chou, & Johnston 1958		Corak & Satterthwaite 1956 Goodman 1957 Keesom & van den Ende 1932 Lange 1924 Rodebush 1923		Aven, Craig, Waite, & Wallace 1956 Kothén & Johnston 1953 Wolcott 1955	
Other refs.	Dauphinee, MacDonald, & Preston-Thomas 1954 Martin 1958 Parkinson & Quarrington 1955 Pickard & Simon 1948 Rayne 1954		Clusius & Losa 1955 Desirant 1947 Keesom & Desirant 1941 Mendelssohn 1941 Wolcott 1955 Worley, Zemansky, & Boorse 1955		Keesom & van Laer 1936, 1937, 1938 Ramanathan & Srinivasan 1955		Estermann, Friedberg, & Goldman 1952 Kelley 1944	

See notes at end of table.

TABLE 4. *Specific heat and enthalpy—Continued*

Metals—Continued

<i>T</i>	Tungsten		Zinc	
	<i>C_p</i>	<i>H—H₀</i>	<i>C_p</i>	<i>H—H₀</i>
° <i>K</i>	<i>j g⁻¹ deg⁻¹ K</i>	<i>j g⁻¹</i>	<i>j g⁻¹ deg⁻¹ K</i>	<i>j g⁻¹</i>
1	0.000 0074	0.000 0037	0.000 011	0.000 005
2	.000 0158	.000 0152	.000 028	.000 023
3	.000 0262	.000 0360	.000 058	.000 065
4	.000 0393	.000 0685	.000 11	.000 14
6	.000 0783	.000 182	.000 29	.000 53
8	.000 141	.000 396	.000 96	.001 6
10	.000 234	.000 765	.002 5	.005 0
15	.000 725	.002 97	.011	.034
20	.001 89	.009 27	.026	.125
25	.004 21	.023 7	.049	.31
30	.007 83	.053 4	.076	.62
40	.018 4	.181	.125	1.62
50	.033 2	.436	.171	3.11
60	.048 3	.843	.208	5.01
70	.060 5	1.39	.236	7.23
80	.071 5	2.05	.258	9.70
90	.081 0	2.81	.277	12.38
100	.088 8	3.66	.293	15.24
120	.101	5.57	.319	21.38
140	.110	7.68	.337	27.96
160	.117	9.95	.350	34.85
180	.122	12.3	.360	41.95
200	.125	14.8	.367	49.22
220	.128	17.4	.373	56.62
240	.130	20.0	.378	64.12
260	.132	22.6	.382	71.71
280	.134	25.3	.386	79.39
300	.136	28.0	.390	87.15
Sources of above data	Horowitz & Daunt 1953 Lange 1924 Rayne 1954 Wolcott 1955		Bronson & Wilson 1936 Clusius & Harteck 1928 Silvidi & Daunt 1950 Smith 1955	
Other refs.	Silvidi & Daunt 1950 Zwicker 1928		Keesom & Kok 1934 Keesom & van den Ende 1932	

See notes at end of table.

TABLE 4. *Specific heat and enthalpy—Continued*Alloys ν

T	Constantan α † 60 Cu 40 Ni		Monel τ † 67 Ni 30 Cu 1.4 Fe 1 Mn		Wood's metal σ † 12.5 Sn 12.5 Cd 25 Pb 50 Bi	
	C_p	$H-H_0$	C_p	$H-H_0$	C_p	$H-H_0$
$^{\circ}K$	$fg^{-1}deg^{-1}K$	fg^{-1}	$fg^{-1}deg^{-1}K$	fg^{-1}	$fg^{-1}deg^{-1}K$	fg^{-1}
1	0.000 11	0.000 06	0.000 11	0.000 054	0.000 02	0.000 003
1.5	-----	-----	-----	-----	-----	-----
2	.000 23	.000 23	.000 22	.000 22	.000 06	.000 022
3	.000 35	.000 52	.000 34	.000 50	.000 24	.000 154
4	.000 49	.000 94	.000 47	.000 90	.000 62	.000 516
6	.000 80	.002 21	.000 78	.002 15	.002 9	.003 57
8	.001 19	.004 19	.001 2	.004 1	.007 6	.013 8
10	.001 69	.007 04	.001 7	.007 0	.013 4	.034 7
15	.003 58	.019 8	.003 7	.020 0	.029 7	.142
20	.006 8	.044 6	.007 1	.046	.046 0	.331
25	.013 1	.093 6	.013	.095	-----	-----
30	.021 6	.179	.021	.178	-----	-----
40	.047 6	.514	.045	.50	-----	-----
50	.083	1.166	.078	1.11	-----	-----
60	.119	2.18	.11	2.06	-----	-----
70	.153	3.54	.15	3.4	-----	-----
80	.184	5.23	.18	5.0	-----	-----
90	.213	7.21	.21	7.0	-----	-----
100	.238	9.47	.24	9.3	-----	-----
120	.279	14.64	.28	14.5	-----	-----
140	.310	20.56	.31	20.5	-----	-----
160	.333	27.00	.34	27.0	-----	-----
180	.349	33.83	.36	34.0	-----	-----
200	.362	40.94	.37	41.3	-----	-----
220	.37	48.3	.39	48.9	-----	-----
240	.38	55.9	.40	56.8	-----	-----
260	.39	63.6	.41	64.9	-----	-----
280	.40	71.5	.42	73.1	-----	-----
300	.41	79.5	.43	81.5	-----	-----
Sources of above data.	Eucken & Werth 1930. Keesom & Kurrelmeyer 1940.		Hampton & Mennie 1932. Keesom & Kurrelmeyer 1940.		Parkinson & Quarrington 1954.	

See notes at end of table.

TABLE 4. *Specific heat and enthalpy—Continued*Other inorganic substances ^u

<i>T</i>	Carbon dioxide		Diamond ^v		Graphite		Ice	
	<i>C_p</i>	<i>H</i> − <i>H</i> ₀	<i>C_p</i>	<i>H</i> − <i>H</i> ₀	<i>C_p</i>	<i>H</i> − <i>H</i> ₀	<i>C_p</i>	<i>H</i> − <i>H</i> ₀
^o <i>K</i>	<i>jq</i> ^{−1deg} ^{−1} <i>K</i>	<i>jq</i> ^{−1}	<i>jq</i> ^{−1deg} ^{−1} <i>K</i>	<i>jq</i> ^{−1}	<i>jq</i> ^{−1deg} ^{−1} <i>K</i>	<i>jq</i> ^{−1}	<i>jq</i> ^{−1deg} ^{−1} <i>K</i>	<i>jq</i> ^{−1}
1					0.000 005	0.000 002	0.000 015	0.000 004
2					.000 027	.000 016	.000 12	.000 061
3					.000 070	.000 062	.000 41	.000 31
4					.000 144	.000 168	.000 98	.000 98
6					.000 33	.000 61	.003 3	.004 9
8					.000 64	.001 56	.007 8	.015 6
10			0.000 018	0.000 17	.001 14	.003 3	.015 2	.038
12							.026 5	.079
14							.043	.148
15	0.051	0.22	.000 053	.000 66	.003 3	.014 2		
16							.065	.255
18							.090	.410
20	.117	.63	.000 122	.001 87	.006 3	.038	.114	.615
25	.203	1.43	.000 235	.004 38	.010 3	.079		
30	.294	2.67	.000 404	.008 87	.015 5	.143	.229	2.33
40	.446	6.40	.000 979	.027 8	.027	.36	.340	5.18
50	.580	11.55	.001 95	.068 8	.042	.70	.440	9.09
60	.683	17.89	.003 41	.144	.058	1.20	.535	13.97
70	.758	25.11	.005 92	.276	.077	1.87	.627	19.78
80	.816	32.99	.009 34	.489	.097	2.74	.716	26.49
90	.866	41.41	.014 0	.821	.118	3.81	.801	34.06
100	.906	50.3	.020 4	1.31	.140	5.10	.882	42.47
110	.943	59.5						
120	.980	69.1	.039 0	2.97	.188	8.37	1.03	61.6
130	1.015	79.1						
140	1.050	89.4	.065 8	5.94	.240	12.65	1.16	83.5
150	1.083	100.1						
160	1.119	111.1	.102	10.7	.296	18.0	1.29	108.0
170	1.158	122.5						
180	1.199	134.3	.145	17.8	.355	24.5	1.43	135.2
190	1.243	146.5						
200			.195	27.5	.414	32.2	1.57	165.1
220			.252	40.3	.474	41.1	1.72	197.9
240			.314	56.6	.535	51.2	1.86	238.7
260			.380	76.5	.595	62.5	2.01	272.4
270							2.08	292.8
273.15							2.10	299.4
280			.447	100	.656	75.0		
300			.518	128	.716	88.7		
Sources of above data.	Giauque & Egan 1937.		Burk & Friedberg 1958. Desnoyers & Morrison 1958. De Sorbo 1953.		Keesom & Pearlman 1955. De Sorbo & Tyler 1953.		Giauque & Stout 1936. Simon 1923.	
Other refs.	Eucken 1916. Eucken & Hauck 1928.		Berman & Poulter 1953. Pitzer 1938. Robertson, Fox, & Martin 1936.		Bergenslid, Hill, Webb, & Wilks 1954. Jacobs & Parks 1934.		Barnes & Maass 1930. Duyckaerts 1945.	

See notes at end of table.

TABLE 4. *Specific heat and enthalpy*—Continued

Other inorganic substances—Continued

<i>T</i>	Magnesium oxide* MgO		Pyrex glass		Quartz, SiO ₂		Silica glass, SiO ₂	
	<i>C_p</i>	<i>H</i> − <i>H</i> ₀	<i>C_p</i>	<i>H</i> − <i>H</i> ₀	<i>C_p</i>	<i>H</i> − <i>H</i> ₀	<i>C_p</i>	<i>H</i> − <i>H</i> ₀
° K	<i>jq</i> −1deg −1 K	<i>jq</i> −1	<i>jq</i> −1deg −1 K	<i>jq</i> −1	<i>jq</i> −1deg −1 K	<i>jq</i> −1	<i>jq</i> −1deg −1 K	<i>jq</i> −1
1			0.000 0031	0.000 0008				
2			.000 025	.000 013				
3			.000 084	.000 064				
4			.000 201	.000 201				
6			.000 753	.001 04				
8			.002 09	.003 94				
10			.004 19	.010 0	0.0007	0.001	0.0045	0.011
15			.013 7	.052 5	.0040	.012	.0126	.052
20	0.0022	0.011	.027 4	.154	.0113	.049	.0244	.143
25	.0036	.025			.0221	.131	.0379	.299
30	.0059	.048			.0353	.273	.0519	.524
35	.0090	.084						
40	.0131	.139			.0653	.773	.0808	1.186
45	.0182	.217						
50	.0243	.322			.0969	1.583	.111	2.15
60	.041	.64			.129	2.71	.141	3.41
70	.073	1.20			.162	4.17	.172	4.97
80	.113	2.13			.195	5.95	.204	6.85
90	.159	3.48			.228	8.07	.236	9.05
100	.208	5.31			.261	10.51	.268	11.57
120	.312	10.5			.325	16.37	.331	17.56
140	.42	17.8			.385	23.48	.391	24.77
160	.51	27.0			.441	31.75	.446	33.14
180	.60	38.1			.494	41.1	.497	42.6
200	.68	50.9			.543	51.5	.544	53.0
220	.74	65.1			.588	62.8	.588	64.3
240	.80	80.6			.631	75.0	.629	76.5
260	.85	97.2			.671	88.0	.668	89.5
280	.90	114.7			.709	101.8	.704	103.2
300	.94	133.1			.745	116.4	.738	117.6
Sources of above data	Giauque & Archibald 1937		Smith & Wolcott 1956		Anderson 1936 Westrum 1955		Simon 1922 Simon & Lange 1926 Westrum 1955	
Other refs.	Parks & Kelley 1926				Gunther 1921			

See notes at end of table.

TABLE 4. *Specific heat and enthalpy—Continued*Organic substances ^{x, y}

<i>T</i>	Araldite		Bakelite varnish ^a		Glyptal		GR-S rubber ^{a'}	
	<i>C_p</i>	<i>H</i> − <i>H</i> ₀	<i>C_p</i>	<i>H</i> − <i>H</i> ₀	<i>C_p</i>	<i>H</i> − <i>H</i> ₀	<i>C_p</i>	<i>H</i> − <i>H</i> ₀
° <i>K</i>	<i>jq</i> −1deg −1 <i>K</i>	<i>jq</i> −1	<i>jq</i> −1deg −1 <i>K</i>	<i>jq</i> −1	<i>jq</i> −1deg −1 <i>K</i>	<i>jq</i> −1	<i>jq</i> −1deg −1 <i>K</i>	<i>jq</i> −1
1					0.00003	0.000007		
1.5	0.000 06	0.000 01						
2	.000 24	.000 08			.0002	.00011		
3	.000 89	.000 60			.0007	.0006		
4	.002 25	.002 10	0.0046	0	.002	.002		
5							0.004	0.005
6	.008 2	.011 7	.0086	.0130	.007	.010		
8	.016 9	.036 7	.0134	.0347	.014	.03		
10	.027 2	.080 7	.0192	.0672	.02	.07	.028	.07
15	.054 2	.284	.0418	.216	.06	.26	.070	.31
20	.081 1	.623	.0667	.487	.11	.67	.113	.77
25			.093	.886	.16	1.3	.155	1.44
30			.121	1.42	.20	2.2	.196	2.32
40			.179	2.91	.29	4.7	.272	4.66
50			.237	4.99	.38	8.1	.338	7.72
60			.293	7.64	.49	12	.399	11.40
70			.347	10.8	.62	18	.455	15.68
80			.400	14.6	.79	25	.509	20.50
90			.449	18.8	.97	34	.562	25.86
100					1.15	44	.612	31.74
120							.711	45.0
140							.811	60.2
160							.911	77.4
180							1.01	96.7
200							1.12	118.0
210							1.34	130.0
212							1.66	133.3
220							1.68	146.1
240							1.73	180.1
260							1.78	215.2
280							1.84	251.4
300							1.90	288.7
Sources of above data	Parkinson & Quarrington 1954	Hill & Smith 1953	Keesom & Seidel 1959 Pearlman & Keesom 1952		Rands, Ferguson, & Prather 1944			

See notes at end of table.

Organic substances^c—Continued

<i>T</i>	Natural rubber hydrocarbon ^{4f}		Polyethylene		Polyvinyl alcohol		Teflon (molded) ^{4f}	
	<i>C_p</i>	<i>H-H₀</i>	<i>C_p</i>	<i>H-H₀</i>	<i>C_p</i>	<i>H-H₀</i>	<i>C_p</i>	<i>H-H₀</i>
^{° K} 5	<i>fg</i> ^{-1deg-1} <i>K</i>	<i>fg</i> ⁻¹	<i>fg</i> ^{-1deg-1} <i>K</i>	<i>fg</i> ⁻¹	<i>fg</i> ^{-1deg-1} <i>K</i>	<i>fg</i> ⁻¹	<i>fg</i> ^{-1deg-1} <i>K</i>	<i>fg</i> ⁻¹
10							0.0024	0.003
15	0.073	0.32					.018	.047
20	.117	.80					.048	.21
25							.076	.52
							.102	.97
30	.204	2.41					.125	1.54
40	.282	4.84					.165	2.99
50	.352	8.01					.202	4.83
60	.418	11.87	0.418	0	0.257	0	.238	7.02
70	.480	16.36	.496	4.57	.331	2.95	.274	9.59
80	.537	21.45	.561	9.84	.388	6.55	.312	12.52
90	.596	27.12	.619	15.7	.436	10.7	.350	15.83
100	.646	33.34	.676	22.2	.478	15.3	.386	19.51
120	.75	47.3	.778	36.8	.546	25.5	.457	27.9
140	.84	63.2	.872	53.2	.624	37.2	.525	37.7
160	.94	81.0	.971	71.7	.713	50.5	.598	49.0
180	1.03	100.7	1.07	92.1	.798	65.7	.677	61.7
190	1.08							
195	1.10							
200	1.44		1.17	114	.879	82.4	.741	75.9
205	1.60							
210	1.61							
220	1.64	155.0	1.28	139	.959	101	.798	91.3
240	1.70	188.4	1.43	166	1.05	121	.853	107.8
260	1.75	222.9	1.63	196			.913	125.5
280	1.81	258.4					1.01	144.6
290	1.84	276.6						
300	1.89	295.3						
310							1.02	179.3
Sources of above data	Bekkedahl & Mattheson 1934		Sochava & Trapeznikova 1957		Sochava & Trapeznikova 1957		Furukawa, McCoskey, & King 1952	
Other refs.							Noer, Dempsey, & Gordon 1959	

^a Superconducting.

^b In germanium the electronic specific heat is markedly dependent on impurities. The values given are for pure germanium (negligible electronic specific heat).

* α -Iron is the form that is thermodynamically stable at low temperatures. It has the body-centered cubic lattice which is the basis of the ferritic steels.

^d γ -Iron is stable between 910° and 1,400° C. It has the face-centered cubic structure which is the basis of the austenitic steels. Since pure γ -iron is not stable at low temperatures the above values were calculated by application of the Kopp-Neumann rule to experimental data on two austenitic Fe-Mn alloys and are of uncertain accuracy.

* Superconducting transition temperature.

α -Manganese is stable at all temperatures up to about 730° C. A small peak in C_p is found centering at 95° K which is due to an antiferromagnetic transition. The data of Armstrong and Grayson-Smith, Elson, Grayson-Smith, and Wilhelm, and Wolcott in the region in up to 20° K form a self-consistent set that is 20 to 30 percent higher than the data of Goodenough, and Morosoff, and Guthrie, and Heidberg, and Goldman. The latter have been adopted because these authors presented more conclusive evidence of the chemical and phase purity of their samples.

* β -Manganese, a form that is stable between 730° and about 1,100° C, was measured by Booth, Hoare, and Murphy (1955) but only in the range 12° to 20° K. Their sample was produced by heating ordinary (alpha) manganese to 1,120° C in argon, then quenching in water. Following are selected values of C_p in $J\ g^{-1}\ deg^{-1}\ K$: 12° K 0.0112; 15° K 0.0135; 20° K 0.0214.

γ -Manganese is a ductile form that is stable between about 1,100° and 1,350° C when pure. It is often found as a separate phase in manganese alloys. The sample measured by Shomate was produced by electrolytic deposition.

ⁱ Superconducting transition temperature of mercury.

j Melting temperature of mercury.

* The data of Zhou, White, and Johnston cover the range, 1.5° to 30° K while the compilation of Kelley (1949) gives best values for room temperature and above. Between 30° and room temperature no modern experimental data are to be found. The values in this region given here are estimates. While the accuracy at 2 to 30° and at 300° K is of order 1 percent, the estimated values between 30° and 300° K are more uncertain and may be in error by as much as 10 percent in the region 40° to 100° K.

¹ In silicon the electronic specific heat, γT , is markedly dependent on impurities. Values of the coefficient, γ , from zero to $2.4 \times 10^{-6} \text{ J g}^{-1} \text{ deg}^{-2} \text{ K}$ have been reported. The values in the above table are for pure silicon ($\gamma=0$).

It has recently been shown (Barrett 1956, Hull & Rosenberg 1959) that sodium partially transforms at low temperatures from the normal body-centered cubic structure to close-packed hexagonal. The transformation is of the martensitic type and is promoted by cold-working at the low temperatures. Inasmuch as none of the calorimetric measurements on sodium were accompanied by crystallographic analysis, the tabulated data below 100° K are to some degree ambiguous.

^a Superconducting transition temperature of tin.

• Superconducting transition temperature of tantalum.

^a In addition to the alloys in the table, 63S aluminum alloy (Alloy 6063: Mg 0.7%, Si 0.3%, Fe 0.2% by wt) has been measured from 2° to 19° K in the annealed and fully-hardened conditions by Otter (1959). Except for the region, 5° to 10° K, where his results were least certain, the specific heats averaged about 2 percent lower than the data for pure aluminum in table 4. The two conditions were the same within a percent. For most engineering purposes the data for pure aluminum should represent this alloy within a few percent up to 300° K.

The name "Constantan" covers a range of compositions centering on 55 wt percent Cu, 45 wt percent Ni. The above alloy is an extreme example. Other Constantans should have specific heats within 5 percent of the values in the table. The published data extended only up to 200° K. The data given in the region, 200° to 300° K, were estimated by the Kopp-Neumann rule. Specific heats of other compositions in the Cu-Ni alloy series have been determined by Aoyama and Kanda 1941, Grew 1934, and Keesom and Kurrelmeier 1940.

* The data from 1° to 20° K result from an interpolation between the 80Ni 20Cu and 60Ni 40Cu alloys measured by Keesom and Kurelmeyer. Between 20° and 90° K, where the data of Hampton and Mennie begin, the specific heat was estimated by the Kopp-Neumann rule. For both of these calculations, it was assumed that the composition 70Ni 30Cu (by weight) would be adequately representative.

* There was evidence of a superconducting transition at 4.8° K. If this interpretation is correct, the tabulated values below this temperature apply to the superconducting state.

(Notes continued on page 20)

[†] Weight percent.

^u To the data in this table on various forms of carbon may be added measurements on an *activated charcoal* by Simon and Swain (1935). No other characteristics of their sample were furnished, and the data were of low precision. The specific heats of adsorbents probably depend on their structure and surface area, and so may vary from sample to sample. Simon and Swain's specific heats were nearly linear with temperature and were much higher than those of the nearest related substance, graphite. Following are selected values in $J g^{-1} \text{ deg}^{-1} \text{ K}$: 20° K 0.042, 50° K 0.087, 95° K 0.16.

^v Diamond is found in two varieties, known as types I and II, which differ mainly in their optical properties. It is generally accepted that the specific heats of the two types are practically the same. However, the only specific heat measurements in which the crystals were identified as to type and segregated (Robertson et al.) apparently were of low precision and do not provide satisfactory confirmation of this assumption.

^w The data of Parks and Kelley are believed to be the most representative of bulk crystalline MgO but unfortunately do not extend below 94° K. Accordingly we have used the more complete data of Giauque and Archibald, even though they were obtained using a fine powder sample and appear to be too high on that account. The extra specific heat due to the surface can be estimated by comparison with the data of Parks and Kelley and also by fitting the data below 70° K (approx. $\theta_0/12$) with the expression $C = aT^2 + bT^3$, in which the first term gives the surface contribution [Keesom and Pearlman, *Handbuch der Physik* XIV, 332-3 (1956)]. If this interpretation is correct one finds that the surface term amounts to about one-third of the total specific heat at 20°, about 5 percent at 100°, and is negligible at 300° K.

^x Furukawa, McCoskey, & King (1953) have summarized the available data on the two elastomers presented here, GR-S rubber and natural rubber hydrocarbon and also Hycar OR-15, polyisobutylene, two other butadiene-styrene polymers, and two polybutadienes. Only the GR-S and Hycar OR-15 were commercial elastomers, and the composition of the latter was unknown. How-

ever it may be helpful to note that all were within about 10 percent of one another except in the region of their glass transitions (brittle points) where the differences were greater. The transition temperatures of these polymers lay in the region, 190° to 250° K.

^y Lucite was measured from 1.4° to 4.2° K by Noer, Dempsey, and Gordon (1959). They found the specific heat in $J g^{-1} \text{ deg}^{-1} \text{ K}$ to be given by $35 \times 10^{-6} T^3$.

^z Formite V11105.

^{aa} 1-3 butadiene, 25 wt percent styrene.

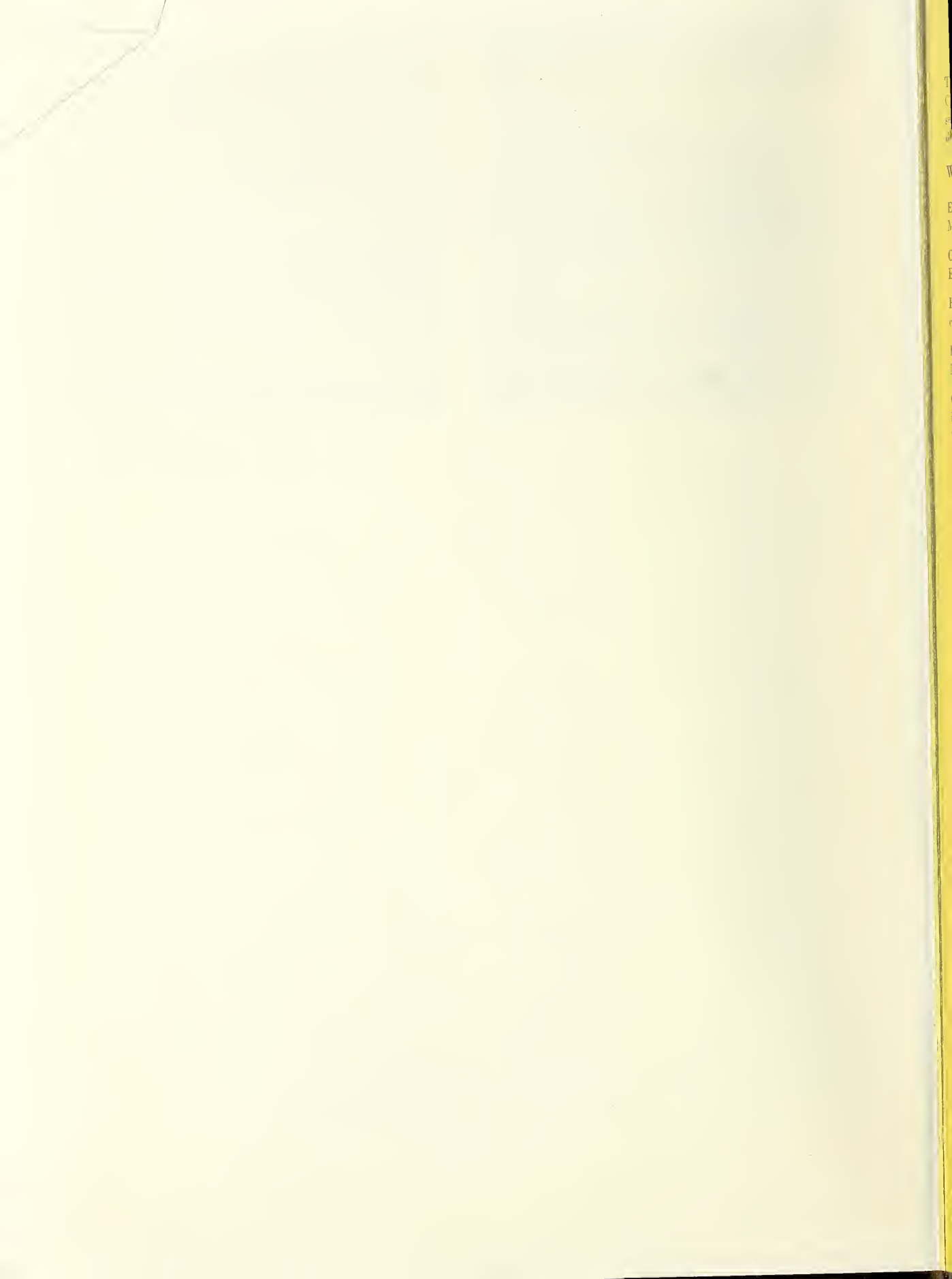
^{bb} Second-order transformation. Thermal hysteresis occurs at temperatures immediately below this.

^{cc} Polystyrene was measured from 1.4° to 4.2° K by Noer, Dempsey and Gordon (1959). They found the specific heat in $J g^{-1} \text{ deg}^{-1} \text{ K}$ to be given by $63 \times 10^{-6} T^3$.

^{dd} These data apply to pure amorphous hydrocarbon polymer extracted from latex. Commercial natural rubber differs from this by containing various additives and having been vulcanized. No low-temperature data for vulcanized rubber have been found, and the above data are presented as being the closest available approximation. A second-order transformation (glass transformation) occurs at about 200° K. The data in this region are the least applicable to other varieties of rubber since the temperature and shape of the transition will be rather strongly affected by compounding and vulcanization.

^{ee} Furukawa et al., also presented data on powdered, molded-and-annealed, and molded-and-quenched Teflon. The effects of heat treatment did not exceed 3 percent and were not significant below 150° K. The data indicate a second-order transition at about 160° K and two first-order transitions between 280° and 310° K. Thermal hysteresis occurs in these regions. Because of this effect no data are presented between 280° and 310° K. The values at 5° and 10° K were extrapolated by Furukawa et al. using a Debye function. Their function gives values only one-half as great as the specific heats measured by Noer, Dempsey, and Gordon (1959) from 1.4° to 4.2° K. The latter results are represented "approximately" by the formula $40 \times 10^{-6} T^3$ for specific heat in $J g^{-1} \text{ deg}^{-1} \text{ K}$.

BOULDER, COLO., March 23, 1960



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Radio Communication and Systems. Low Frequency and Very Low Frequency Research. High Frequency and Very High Frequency Research. Modulation Systems. Antenna Research. Navigation Systems. Systems Analysis. Field Operations.

